International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249-6890; ISSN (E): 2249-8001
Vol. 8, Issue 4, Aug 2018, 83-98
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# A STATISTICAL OPTIMIZATION IN ERGONOMIC PARAMETERS INFLUENCING MUSCULOSKELETAL DISORDER IN WORK ENVIRONMENT USING RCR-WOA METHOD

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Original Article

***ABSTRACT***

***Musculoskeletal disorder (MSD) is considerably one of a crucial reason for the cause of work disability all over the world and also it is considered as a more severe issue when compared with the non-fatal injury and illness. MDS is mostly associated with the raise in the cost to the employers on behalf of absenteeism, productivity loss, increasing health care and compensation cost respectively. Subsequently, one of a critical approach is the rectifying, controlling and the curing of the concerned MSD hazard. In this paper an efficient methodology named Random Coefficient Regression Analysis-Whale Optimization Algorithm (RCR-WOA) is being practiced to optimize the ergonomic parameters such as stress and strain of MSD. Henceforth, the evaluated results are statistically scripted and approximated by the Neuber's rule and also to obtain an adequate stress and strain parameters. Sequentially, the distinct performance of the proposed methodology is being compared on the basis of Bilinear Kinematic Hardening. The proposed methodology is mathematically scripted and executed on the working platform of Mat Lab and the performance results are analyzed and compared with existing approaches for better outcomes. Conclusively, based on the overall inquiry the proposed methodology seems to be more efficient and accurate for optimizing the stress and strain MSD parameters in industries when compared with the existing one.***

***KEYWORDS: Musculoskeletal Disorders (MSDs), Random Coefficient Regression Analysis, Whale Optimization Algorithm, Stress & Strain***

**Received**: May 16, 2018; **Accepted**: Jun 06, 2018; **Published**: Jun 27, 2018; **Paper Id**: IJMPERDAUG201810

## 1. INTRODUCTION

Ergonomics has been characterized as the exploration of fitting the activity to the specialist or the specialty of coordinating occupation requests with laborer capacities. An extensive variety of fiery and degenerative conditions influencing the muscles, ligaments, tendons, joints, fringe nerves, and supporting veins are thought to be "Musculoskeletal disorders" (MSD). These incorporate clinical disorders, for example, ligament aggravations and related conditions (tenosynovitis, epicondylitis, bursitis), nerve pressure issue (carpal tunnel syndrome, sciatica), and osteoarthrosis, and less very much institutionalized conditions [1]. MSDs happen in particular ventures and occupations with rates up to three or four times higher than the general recurrence [2]. It is generally acknowledged that MSDs in office laborers are multifactorial and the hazard factors are named a blend of individual, physical and psychosocial factors. Past investigations detailed that individual factors, for example, age, sex and instructive level

are related with MSDs among office laborers. This physical condition makes them helpless to furthest point MSDs. Constrained undertaking assortment and redundant developments, short rest breaks, quick work pace and poor ergonomic workstation, were other physical variables which were identified with MSDs [3].

MSDs are the most critical reason for nonappearance from work in for all intents and purposes all Member States. In a few states, 40% of the expenses of specialists pay are caused by MSDs and up to 1.6% of the total national output (GDP) of the nation itself. Making increasingly and better-quality occupations is a basic target agony, distress and loss of capacity in back, neck and furthest points are regular among working individuals. These diseases are normally named musculoskeletal disorders (MSDs) [4]. Numerous outcome from combined little adequacy powers happen with overtraining, overexertion, tedious exercises, compelling activities, and delayed static situating. Avoidance is hampered by numerous issues. There remains a call for compelling medicines for these regularly incapacitating clutters [5]. Administration of MSDs normally includes a multidisciplinary group approach, incorporating a lessening in workload, expanded rest, push administration, behavioral mediation and physiotherapy [6].

Boundaries to more viable work environment administration of MSD chance include: the broad conviction that hazard emerges generally (or) altogether from physical peril exposures; administrative and direction archives focusing on MSDs. The conventional occupational health and safety (OHS) chance administration worldview, which is ill-suited to oversee MSD chance [7]. Information of hereditary impacts affecting longitudinal examples is critical to anticipate phenotypic movement in longitudinal investigations. A novel nature-propelled meta-heuristic improvement calculation, called Whale Optimization Algorithm (WOA) impersonates the social conduct of humpback whales, and furthermore the calculation is motivated by the air pocket net chasing procedure. It is a typical practice that the worries at scores and problem areas are ascertained flexibly, using customary usage of ostensible anxieties duplicated by the versatile pressure fixation factors, or by elastic finite element analysis (FEA) methods. In 1961 Neuber proposed a strategy for pliancy remedy of elastic notch analysis. This technique is known as Neuber's rule, which was inferred by investigating a kaleidoscopic indented body under monotonic shear loading. From the above perception, the examination is persuaded to streamline the ergonomic parameters caused by MSD, and it is assessed utilizing factual investigation technique. Subsequently the proposed approach can constrain the ergonomic parameters of MSD in industrial sector respectively.

## 2. LITERATURE SURVEY

Musculoskeletal Disorders (MSD) are delicate tissue wounds normally incited by sudden or supported presentation to dreary movement, power, vibration, and cumbersome positions. They can influence the muscles; nerves; ligaments; joints; and ligament in the upper and lower appendages, neck, and lower back. Work environment configuration assumes a pivotal part in the improvement of a MSD and they are most normally found in businesses described by utilizing work that spots delayed physical strain on specific parts of the body. Buckle et al [8] considers the issue from a wide assortment of frameworks needs and perspectives. Contemporary ergonomics focuses on the criticalness of a participatory methodology to counteractive action and answer finding, and confirmation in help of this is displayed. The last assessment considers the utilization of ergonomics mastery to understanding musculoskeletal issue among these the use of computer innovation. David et al [9] outlined a scope of techniques that have been created for the assessment of introduction to peril components for business related musculoskeletal disorders.

Numerous considerable publications were found about specific exposure assessment techniques. Hagberg et al [10] made a conference and workshop discussions for the exposure assessment. Musculoskeletal disorders (MSD) have turn out to be the most current form of the professional disease in France so, such troubles and disorders, in relation to working conditions, are complicated mechanisms, regularly expressed by chronic pain and related with practical troubles and even disability. The majority of researchers are currently in agreement in affirming the multidimensional aspect of these disorders in biomechanical and psychological terms. Lanfranchi et al [11] listed and reviewed the main risk elements leading to such consequences. These epidemiological and psychological factors will be related to francophone clinical and ergonomic concepts and positions. This perspective is oriented more toward the "meaning of activity" with a clinical and a psychodynamic approach. Bruno et al [12] reviewed the literature to make clear the physiological effects and advantages of, and misconceptions about, stretches used to minimize musculoskeletal disorders. Nine databases have been reviewed to pick out research exploring the effectiveness of stretching to prevent work-related musculoskeletal disorders. Included studies were reviewed and their methodological quality was assessed using the PEDro scale. The physiological effects of stretches may additionally contribute to reducing discomfort and pain. However, if other measures are not in region to remediate their causes, stretches may suppress awareness of risks, ensuing in extra debilitating injuries. If inadequately performed, stretches may additionally also purpose or aggravate injuries. Careful analysis and stretching program design are required earlier than implementing stretches. Seven studies evaluating the effectiveness of stretching to stop musculoskeletal problems in different occupations have been recognized and reviewed. L. Abásolo et al [13] estimate whether a population-based clinical program offered to sufferers with recent-onset work disability caused by MSDs is cost-effective. Jeang et al [14] researched to decide the optimum parameter values for ergonomic product designs via computer musculoskeletal modeling (CMM) and multi-objective optimization (MOO). The multiple-muscle activities measured by using the AnyBody (AB) Modeling System are used to improve the functional relationships with product design parameters by way of a statistical method, such as the design of experiment (DOE) and Response Surface Methodology (RSM), is adopted in the present approach. Such functional relationships are considered as objective functions which will be further formulated by means of compromise programming (CP) for multi-objective optimization MOO) problems.

MSDs can meddle with activities at work and can prompt diminished profitability, infection nonappearance, and steady word related handicap. Manjunath et al [15] intended to examine the joints, the utilization of finite element method (FEM) approach with various contextual investigations and to think about the capacity of ergonomics in counteracting business related MSD issue. Flexible Multibody System Dynamics (FMSD) is a reenactment approach that can be utilized to find out about the direct of the mechanical structures that comprises of at least one deformable bodies. A deformable body can be displayed utilizing an assortment of systems while the drifting casing of reference definition is an extensively utilized approach. In that approach, adaptability inside Multibody System Dynamics (MSD) is portrayed through utilizing the Finite Element Analysis (FEA) with a modular diminishment approach. Marcé-Nogué et al [16] inferred that utilization of this technique is feasible and condition well-disposed for the find out about of encouraging systems in vertebrate developments when a dynamic reaction be assessed. In factual investigations of longitudinal qualities, random regression test-day model (RR-TDM) has clear favorable circumstances over different models. Kang et al [17] assessed the execution of the model coordinating both single-step and RR-TDM forecast techniques, called single-step random regression test-day model (SS RR-TDM), in correlation with the family based RR-TDM and genomic best linear unbiased prediction (GBLUP) demonstrate while SeyedaliMirjalili et al [18] tried WOA with 29 numerical streamlining issues and 6 auxiliary plan issues. Considering the examination of strong joints which is influenced by MSD Daniel Kujawski et al [19] gave a

speculation of Neuber's rule for a fast and simple versatile/plastic score investigation. The proposed generalization allows for a numerical and/or graphical solution for any notch geometry as well as its associated stress concentration factor, $k_t$, and fatigue notch factor, $k_f$. It is shown that the so called Neuber's “master” curve, involved in such analysis, is unique and is only material dependent and also Luis David *et al* [20] focused on vibration response-based health monitoring for an operating wind turbine, which features time-dependent dynamics under environmental and operational uncertainty. A Gaussian Mixture Model Random Coefficient (GMM–RC) model based Structural Health Monitoring framework postulated in a companion paper is adopted and assessed.

## 3. PROPOSED RESEARCH WORK

Musculoskeletal disorders incorporate an extensive variety of provocative and degenerative conditions influencing the human body. Musculoskeletal disorders (MSDs) are boundless in numerous nations, with significant expenses and effect on personal satisfaction. MSDs happen in specific businesses and occupations with rates up to three or four times higher than the general recurrence. The physical activity includes that are as often as possible referred to as hazard factors for MSDs, in light of both trial science and epidemiologic examinations. Physical ergonomic highlights of work much of the time referred to as hazard factors for MSDs incorporate fast work pace and redundant movement, compelling efforts, non-nonpartisan body stances, and vibration. This research rouses to diminish the ergonomic parameters in MSD in work puts by factual assessment. Industrial data processing is one of the fastest growing research topics in the information industry in recent years due to the wide availability of the huge amounts of data and the crucial need to transform such data to useful information. In recent years, hybrid metaheuristics have been used by many researchers in the field of optimization. Nature-inspired meta-heuristic algorithms solve optimization problems by mimicking biological or physical phenomena.

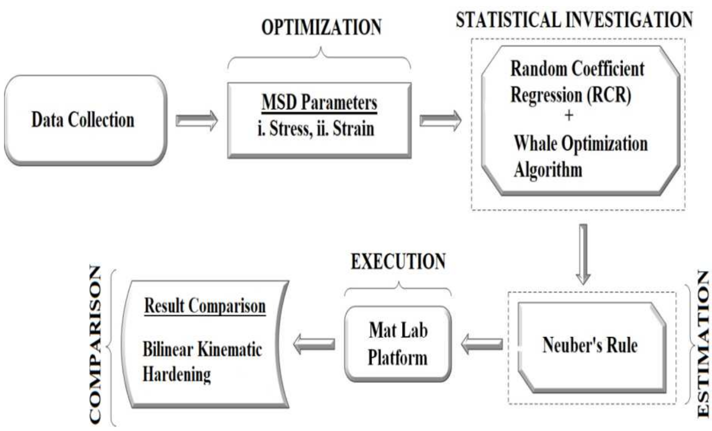


**Figure 1: Architecture of Proposed RCR-WOA Method**

In this paper, Random Coefficient Regression Analysis (RCR) is hybridized in to Whale Optimization Algorithm (WOA) to improve the regression accuracy. Random coefficient regression has achieved advantages over industrial platforms due to its attractive features and promising generalization performance. Proper parameters setting can improve the RCR regression accuracy. However, inappropriate parameters in RCR lead to over-fitting or under-fitting. Different parameter settings can cause significant differences in performance. Therefore, selecting optimal hyper-parameter is a major role in RCR design. In order to improve the performance of RCR, WOA is applied to select the most appropriate training parameters of RCR. WOA requires only the fitness values to determine their search. However, considering the

difficulty in obtaining the fitness value, due to impossibility to run a real system for each parameter combination, RCR would be an option as a fitness estimator. The objective of WOA is to shorten the time to compute and optimize the fitness value. Hence, RCR would be used as an objective function for the WOA optimization process, to generate the outputs from the inputs. The obtained statistical results from the proposed RCR-WOA is estimated by the Neuber's rule to find the accurate stress and strain parameters. A performance comparison is carried out to find the efficiency of the proposed output with the Bilinear Kinematic Hardening outcomes. Ultimately, utilizing of these statistical evaluations the extreme level of stress and strain parameters of MSD can be reduced.

**3. 1. Statistical Investigation**

**Random Coefficient Regression**

A single-step random regression test-day model (SS RR-TDM) with longitudinal phenotypic variable is created and it is being decomposed as follows:

$$y_{ijt} = b_i + \sum_{k=1}^{n_f} \beta_k \varphi_k(t) + \sum_{k=1}^{n_a} a_{kj}\varphi_k(t) + \sum_{k=1}^{n_p} p_{kj}\varphi_k(t) + e_{ijt} \quad (1)$$

Where $y_{ijt}$ is the phenotypic record of individual $j$ at time point $t$ within the $i$ th level of fixed effect $b$ ; $\beta_k$ is the $k$ th fixed regression coefficient; $a_{kj}$ and $p_{kj}$ are the $k$th random regression coefficient for additive genetic and permanent environmental effects, respectively, for individual $j$ ; $\varphi_k(t)$ is the $k$th covariate for the observation of individual $j$ made at time point $t$; $n_f$ , $n_a$ and $n_p$ are the numbers of fixed, random additive and random permanent environmental covariates; and $e_{ijt}$ is the time-independent random residual error for each observation. Specifically, permanent environmental effects are the permanent and non-transmissible effects, such as dominance effects, epistatic effects and permanent stunting when young. It was different between individuals, and therefore it was assumed to be a random effect. In model (1), fixed and random regressions can be defined as covariance functions with different expressions. The matrix representation of the model is accordingly denoted as:

$$y = X_1 b_1 + X_2 b_2 + Q_a + Z_p + e \quad (2)$$

Where $y$ is the vector of phenotypes, $b_1$ is the vector of fixed effects, $b_2$ is the vector of fixed regression coefficients, $a$ and $p$ are vectors of random regressions for additive genetic effect and permanent environmental effect, $X_1$, $X_2$, $Q$ and $Z$ are design matrices of $b_1$ , $b_2$ , $a$ and $p$ , respectively; $e$ is the vector of residuals. $X_1$ contains indictor variables for time-independent fixed effects (ones and zeroes); and $X_2$, $Q$ and $Z$ contain time-dependent covariates. It was assumed that

$$\mathrm{var}\begin{bmatrix} a \\ p \\ e \end{bmatrix} = \begin{bmatrix} H \otimes C & 0 & 0 \\ 0 & I \otimes P & 0 \\ 0 & 0 & R \end{bmatrix} \quad (3)$$

Where $I$ is an identity matrix with dimensions equal to the number of effect levels, $\otimes$ is the Kronecker product, $C$ and $P$ are (co)variance matrices of additive genetic and permanent environmental regression coefficients, $R = I\sigma^2_e$ with $\sigma^2_e$ standing for residual variance, and $H$ is the combined relationship matrix. $H$ is defined as:

$$H = \begin{bmatrix} A_{11} + A_{12}A_{22}^{-1}(G_W - A_{22})A_{22}^{-1}A_{12} & A_{12}A_{22}^{-1}G_W \\ G_W A_{22}^{-1}A_{12} & G_W \end{bmatrix} \quad (4)$$

Where, $A_{11}$, $A_{12}$ and $A_{22}$ are partitions of $A$, the numerator relationship matrix based on pedigree, and subscripts 1 and 2 refer to ungenotyped and genotyped individuals, respectively. $G_W$ is derived from an adjusted kinship matrix $G^*$, which is explained in equation 6, and it is constructed by both pedigree and genotype information. It is expressed in the following equation.

$$G_W = (1-w)G^* + wA_{22} \quad (5)$$

$$G^* = \beta G + \alpha \quad (6)$$

Where, $w$ reflects the fraction of genetic variance not being captured by single nucleotide polymorphism (SNP) markers and canalso be used to avoid singular problems of the $G$ matrix, and $G$ is genomic relationship matrix.

$$G = \frac{(M-P)(M-P)'}{2\sum_{j=1}^{n} p_j(1-p_j)} \quad (7)$$

Where, $M$ is a matrix of SNP genotypes for each individual, $P$ is a matrix of 2 times the observed allele frequency of the second allele $p$ at locus $j(p_j)$. Ideally, allele frequencies in base population should be used in the construction of $G$, however, they were not available in most practical situations. In consideration of simplicity in implementation, we used observed allele frequencies of genotyped individuals in our study, which was also a good reference and commonly used in other studies. In principle, the additive genetic variance using $G$ is identical to that using $A$. In Equation (6), $G^*$ was considered as the adjusted $G$ matrix for avoiding potential incompatibility in scale between $G^*$ and $A_{22}$ involved in the $H$ matrix. The corresponding mixed model equations (MME) for equation (2) are:

$$\begin{bmatrix} X'R^{-1}X & X'R^{-1}Q & X'R^{-1}Q \\ Q'R^{-1}X & Q'R^{-1}Q + H^{-1} \otimes C^{-1} & Q'R^{-1}Z \\ Z'R^{-1}X & Z'R^{-1}Q & Z'R^{-1}Z + I \otimes P^{-1} \end{bmatrix} \begin{bmatrix} \hat{b} \\ \hat{a} \\ \hat{p} \end{bmatrix} = \begin{bmatrix} X'R^{-1}y \\ Q'R^{-1}y \\ Z'R^{-1}y \end{bmatrix} \quad (8)$$

In the solutions of this MME, each individual has $n_a$ regression coefficients as predictions for additive genetic effects. Predicted genetic value (PGV) of individual $j$ for any particular time point $t$ of interest, for example, systolic and

diastolic blood pressure at a particular age, could be simply achieved as follows:

$$PGV_{jt} = \sum_{k=1}^{n_a} \hat{a}_{kj}\, \varphi_k(t) \tag{9}$$

Where, $\varphi_k(t)$ and $n_a$ are as described in the equation and $\hat{a}_{kj}$ is the solution for the $k$th regression coefficient of individual $j$. If the accumulated PGV for a period of time is of interest, for example, 305 days' milk yield in dairy cattle or egg production during the first 22 weeks of production in layer chicken, they could be calculated by adding up the PGV at each time point over a specific period.

To exploit potential advantages of SS RR-TDM over its conventional counterparts, genetic/genomic prediction with the two widely used models is performed, that is, regular pedigree-based RR-TDM evaluation approach and the multiple-step method of genomic best linear unbiased prediction (GBLUP). The GBLUP model is explained in the following equation 10.

$$y = \mu 1_n + Z_g + e \tag{10}$$

Where, $y$ is a $n \times 1$vector of the response variable; $\mu$ is the overall mean; $1_n$ is a vector of $n$ones; g is the $n \times 1$vector of additive genomic effects with distribution of $N(0, G\sigma_g^2)$, $Z$ is the corresponding incidence matrix; and $e$ is the vector of random residuals with distribution of $N(0, G\sigma_e^2)$. $G$ is the previously mentioned genomic relationship matrix with 0.02 added to its diagonal elements to avoid singular problems, and $D$ is a diagonal matrix.

It is notable that, in the GBLUP model, both PGV and its de-regressed proof (DRP) were used as response variables in the simulation analyses. Reliabilities of PGV and DRP derivation and the corresponding reliability were calculated. $D$ is an identity matrix for the situation of PGV being used as the response variable; while DRP was considered as the response variable, $D$ was a diagonal matrix with elements $d_{ii} = 1/w_i$, where weighting factor was defined as $w_i = r_{DRP}^2/(1 - r_{DRP}^2)$, with $r_{DRP}^2$being the reliability of DRP. In the regular RR-TDM approach, decomposition of phenotypic value was the same as that in SS RR-TDM except that the additive genetic relationship between individual pairs was described by the A matrix. Solutions of random regression coefficients of additive genetic effects from both regular RR-TDM approach and SS RR-TDM approach were converted to total or average PGV over the particular time period, which was consistent with those estimated in the GBLUP model. The (co)variance components involved in the regular RR-TDM and GBLUP model were estimated using average information restricted maximum likelihood. The (co)variance components used in the SS RR-TDM approach were those estimated with regular RR-TDM model. We employed DMU package to estimate (co) variance components and solve the MME. H and H- 1 matrices were also computed by DMU.

### 3. 2. Whale Optimization Algorithm

Whale optimization (WOA) algorithm is another bio-motivated headway count proposed by Mirjalili. It imitates

the hunting behaviour of humpback whales. The humpback whale jumps around twelve meters down the prey, starting to make bubbles net in a spiral shape and swimming up to the surface to get the prey. This bubbles net is a remarkable method for hunting. The regular lead of the whale optimizer including misuse and investigation stages are portrayed as follow

**Encircling Prey**

At the point when the area of the prey can be characterized by the humpback whale, it begins revolving around the prey. Clearly, the position of the optimal design in the search space is not known, but the WOA assumes that the current best solution is the position of the hunted prey or close to it. After defining the best search agent, the other agents will try to move their position towards it. This activity is spoken to as takes after

$$\vec{D} = \left| \vec{C} . \vec{X}^*(t) - \vec{C}(t) \right| \tag{11}$$

$$\vec{X}(t+1) = \vec{X}^*(t) - \vec{A}.\vec{D} \tag{12}$$

Where, $t$ is the current iteration, $X^*$ is the current best solution, and $X$ represents the positionvector. When there is a better solution, $X^*$ should be updated. The vectors $\vec{A}$ , $\vec{C}$ are calculated by the following equations.

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \tag{13}$$

$$\vec{C} = 2\vec{r} \tag{14}$$

Where, $\vec{a}$ is decreased from 2 to 0 through the iterations in exploration and exploitation phases, and $\vec{r}$ is random value in [0, 1].

**Bubble-Net Attacking Method (Exploitation Phase)**

The humpback whale’s bubble net behavior is achieved by shrinking encircling mechanism, represented in decreasing $A$ in Eq. 13 through the different iterations. Also, when the distance between the whale and prey is calculated, a spiral equation is created between the whale and the prey to mimic the movement of the humpback whales as follows.

$$\vec{X}(t+1) = \vec{D}' e^{bl} \cos(2\pi l) + \vec{X}^*(t) \tag{15}$$

Where $\vec{D}' = \left| \vec{X}^*(t) \vec{X}(t) \right|$ and indicates the obtained best solution so far. This best solution is the distance between the prey and $i^{th}$whale. Also, $b$ is a constant and $l$ is a random number in [−1, 1]. It is noticed that the humpback whales swim in a spiral shape with shrinking circle.

During the iterations, the mathematical model depends on this conditional formula.

$$\vec{X}(t+1)=\begin{cases}\vec{X}^*(t)-\vec{A}.\vec{D} & if\,, p<0.5\\ \vec{D}'e^{bl}\cos(2\pi l)+\vec{X}^*(t) & if\,, p\geq 0.5\end{cases} \tag{16}$$

Where, $p$ is a random number in [0, 1].

**Search for Prey (Exploration Phase)**

In the exploration phase, the whales group search randomly according to the position of each one, compared to the others in the group. $\vec{A}$ vector with random values in [1, -1] forces a search agent to move away from others. The position of a search agent is updated according to a randomly chosen search agent. The mathematical model is as follows.

$$\vec{D}=\left|\vec{C}.\vec{X}_{rand}-\vec{X}\right| \tag{17}$$

$$\vec{D}(t+1)=\vec{X}_{rand}-\vec{A}.\vec{D} \tag{18}$$

Where, $\vec{X}_{rand}$ is a random whale position chosen from the population. In general, WOA algorithm creates a set of random solutions as an initial start. The search agents update their positions in every iteration according to a randomly chosen agent or the current best solution. The best solution is chosen according to the fitness function values. The current solution with least value is chosen as the best solution. The spiral bubbles net decreases the circle around the prey. Finally, the number of iterations is the termination criterion for WOA algorithm.

**3. 3. Fitness Function**

The fitness function is utilized for the unaltered datasets, while the alterable is utilized for the changing datasets as in convolution in hereditary datasets. In optimization techniques, the fitness function is utilized to assess every subset (representing clusters) of the search space after each iteration. In our research, considering the trouble in getting the fitness value, because of inconceivability to run a real system for every parameter mix, RCR would be an alternative as a fitness estimator. The goal of WOA is to shorten the time to compute and optimize the fitness value. Consequently, RCR would be utilized as an objective function for the WOA optimization process, to generate the outputs from the inputs.

**3. 4. Neuber's Rule**

Neuber demonstrated that for a shear-strained prismatic body with an random non-linear stress-strain curve, the geometric mean of the stress and strain concentration factors ($K_\sigma$ and $K_\varepsilon$ ) is equal to the theoretical stress concentration factor $K_t$. This is expressed as follows:

$$K_\sigma K_\varepsilon = K\tau^2 \tag{19}$$

Where $K_\sigma$ is the actual stress concentration factor, $K_\varepsilon$ is the actual strain concentration factor and $K_t$ is the stress concentration factor for a linear elastic material. The stress concentration factor, $K_\sigma$ is the ratio of the notch root stress and the net-section nominal stress.

$$K_{\sigma} = \frac{\sigma}{s} \tag{20}$$

The strain concentration factor, $K_{\varepsilon}$ is the ratio of the notch root strain and the net-section nominal strain $e$

$$K_{\varepsilon} = \frac{\varepsilon}{e} \tag{21}$$

Hence, Neuber's rule is re-written as:

$$\sigma_{\varepsilon} = K_t^2 Se \tag{22}$$

Generally, this is re-written in terms of stress and strain ranges for the case when the stress range remote to the notch is linear elastic:

$$\Delta\sigma\Delta\varepsilon = \frac{(K_t \Delta S)^2}{E} \tag{23}$$

The form presented in the above equation is widely used in fatigue life calculations using the linear static approach. It shows that the product of the notch stress and strain ranges can be estimated by knowing the theoretical stress concentration factor, the applied stress range and the elastic modulus of the material.

## 4. EXPERIMENTAL ANALYSIS AND RESULT DISCUSSIONS

The proposed technique is implemented in the working platform of Mat Lab environment with the system specification. Processor: Intel Core 2 Quad @ 2.5 GHz; RAM: 3GB; Operating System: Windows 7; Mat Lab Version: R 2016a Version 9.0. The prediction of material property in the stir casting process is analyzed in the Mat Lab with the experimented data and the test result are plotted.

### 4. 1 Data Collection

A questionnaire is developed from various musculoskeletal disorders in industrial employers. A survey is undertaken for 16 MSD parameters for 10 set of industries. The objective of the questionnaire is to find out stress and strain parameters of the employees in this set of industries. The developed questionnaire for optimizing the stress and strain parameters of the employees is elaborated in the tabulation below.

**Table 1: Questionnaire for MSD Parameters in Industries**

| Musculoskeletal Symptoms | Health Care and Social Assistance Sector | | Manufacturing Industry | | Transport, Postal and Warehousing | | Construction Sector | | Public Administration and Safety | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F | M | F |
| Joint Pain | 74 | 81 | 50 | 75 | 60 | 45 | 55 | 38 | 52 | 36 |
| Joint Swelling | 2 | 3 | 0 | 2 | 1 | 0 | 2 | 1 | 2 | 1 |
| Joint Stiffness | 1 | 4 | 1 | 2 | 0 | 1 | 0 | 1 | 1 | 2 |
| Muscle Pain | 16 | 17 | 10 | 16 | 15 | 5 | 12 | 11 | 10 | 12 |
| Spine/ Back Pain | 52 | 77 | 51 | 74 | 45 | 42 | 41 | 43 | 35 | 48 |
| Loss of Mobility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deformity of Joint | 1 | 4 | 2 | 5 | 10 | 4 | 7 | 5 | 5 | 2 |

**Table 1: Contd.,**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Deformity of Spine | 0 | 0 | 1 | 1 | 1 | 4 | 2 | 4 | 1 | 1 |
| Inflammation | 28 | 32 | 23 | 17 | 20 | 13 | 28 | 22 | 27 | 20 |
| Burning sensation in muscles | 30 | 45 | 26 | 23 | 24 | 19 | 29 | 15 | 25 | 16 |
| Fingers turned white | 9 | 12 | 5 | 11 | 7 | 12 | 13 | 9 | 10 | 11 |
| Tingling or Numbness | 4 | 8 | 26 | 6 | 2 | 4 | 9 | 8 | 8 | 11 |
| Decreased sweating of hands | 12 | 19 | 18 | 14 | 15 | 17 | 12 | 10 | 7 | 15 |
| Sleep disturbances | 39 | 48 | 36 | 20 | 45 | 35 | 5 | 3 | 2 | 4 |
| Twitching muscles | 18 | 23 | 33 | 19 | 8 | 4 | 11 | 7 | 8 | 6 |
| Fatigue | 9 | 13 | 16 | 5 | 6 | 7 | 13 | 8 | 4 | 1 |
| **Total** | **295** | **386** | **298** | **290** | **259** | **212** | **239** | **185** | **197** | **186** |

**Table 2**

| Musculoskeletal symptoms | Retail Trade Sector | | Education and Training Sector | | Agriculture, Forestry and Fishing Firm | | Professional, Scientific and Technical Services | | Financial and Insurance Services | |
|---|---|---|---|---|---|---|---|---|---|---|
| | M | F | M | F | M | F | M | F | M | F |
| Joint Pain | 61 | 45 | 28 | 32 | 15 | 19 | 18 | 15 | 10 | 14 |
| Joint Swelling | 3 | 2 | 0 | 1 | 0 | 1 | 2 | 1 | 1 | 3 |
| Joint Stiffness | 2 | 0 | 1 | 1 | 3 | 2 | 2 | 2 | 1 | 2 |
| Muscle Pain | 16 | 6 | 12 | 11 | 10 | 12 | 13 | 10 | 14 | 18 |
| Spine/ Back Pain | 40 | 39 | 25 | 23 | 18 | 11 | 10 | 12 | 8 | 6 |
| Loss of Mobility | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deformity of Joint | 8 | 2 | 2 | 5 | 4 | 1 | 4 | 2 | 4 | 4 |
| Deformity of Spine | 1 | 2 | 0 | 2 | 0 | 2 | 1 | 0 | 2 | 1 |
| Inflammation | 31 | 33 | 12 | 15 | 5 | 8 | 4 | 7 | 1 | 6 |
| Burning sensation in muscles | 29 | 18 | 8 | 5 | 3 | 5 | 1 | 9 | 4 | 4 |
| Fingers turned white | 13 | 9 | 3 | 7 | 1 | 3 | 1 | 5 | 1 | 1 |
| Tingling or Numbness | 14 | 7 | 6 | 5 | 1 | 2 | 2 | 2 | 1 | 4 |
| Decreased sweating of hands | 10 | 16 | 5 | 9 | 4 | 8 | 4 | 7 | 3 | 3 |
| Sleep disturbances | 4 | 5 | 1 | 1 | 1 | 3 | 3 | 2 | 1 | 1 |
| Twitching muscles | 11 | 17 | 7 | 4 | 4 | 7 | 3 | 1 | 2 | 1 |
| Fatigue | 2 | 3 | 0 | 1 | 0 | 1 | 2 | 1 | 2 | 0 |
| **Total** | **245** | **204** | **110** | **122** | **69** | **85** | **70** | **76** | **55** | **68** |

In table 1 & 2, M and F represents the male and female category respectively. The questionnaire is developed for generating data for optimizing the musculoskeletal disorder stress and strain parameters in industrial employers. In this questionnaire 16 musculoskeletal disorder symptoms are considered for 10 set of industries.

**Optimized MSD Stress and Strain Parameters in Industries**

The actual stress and strain parameters for both men and female in various industries were calculated and it is tabulated in table 2 in the appendix section. From the actual set of data, the optimization process is being carried out using random coefficient regression analysis hybridized with whale optimization algorithm. The result of optimization in the 10 industries for the MSD parameters is presented in table 3 in the appendix section.

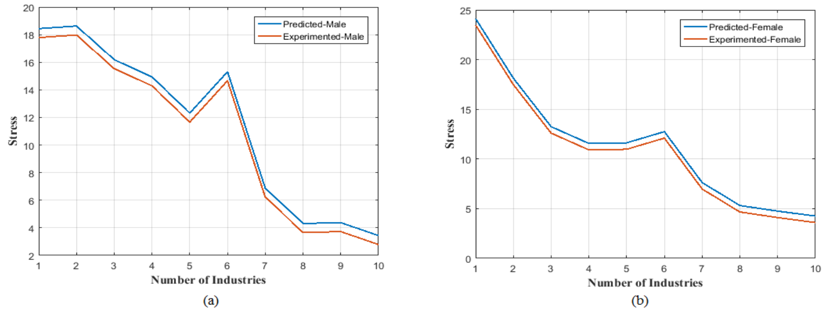


**Figure 2: Comparison of Stress Parameters of (a) Male and (b) Female**

In figure 2, the experimented and predicted values of MSD stress are plotted against different industries. In industries such as health care and social assistance, the stress values are seen to be higher for both the category and the lowest stress values are obtained for financial and insurance services. The maximum stress values are obtained for female category.

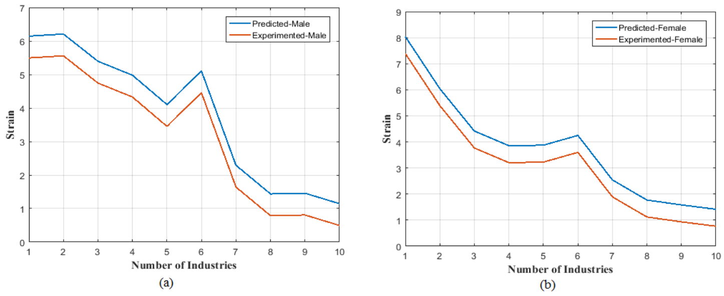


**Figure 3: Comparison of Strain Parameters of (a) Male and (b) Female**

In figure 3, the experimental and predicted values of MSD strain of different industries are shown. The strain values of industries such as professional, scientific and technical services and financial and insurance services are having maximum values for both male and female sections.

**4. 2 Result Comparison**

**Hardening**

The yield foundation for some, materials depends upon at the historical backdrop of loading and evolution of plastic strain. The adjustment in the yield criterion in view of loading is called hardening and is characterized by the hardening rule. Hardening behavior outcomes in an increase in yield stress upon further loading from a state on the yield surface all together that for a plastically distorting material, an expansion in stretch is joined by an increment in plastic strain.

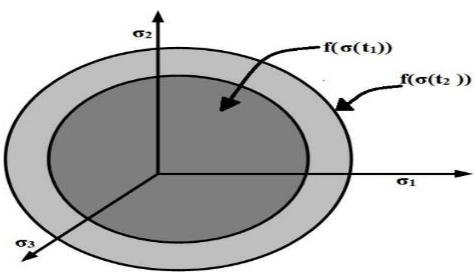


**Figure 4**

Two common types of hardening rules are isotropic and kinematic hardening. Isotropic sort of hardening can model the behavior of materials under monotonic loading and elastic unloading, but often does not provide excellent results for structures that experience plastic deformation after a load reversal from a plastic state. Kinematic hardening is observed in cyclic loading of metals.

It can be used to model behavior such as the Bauschinger effect, where the compressive yield strength reduces in response to tensile yielding. It can also be used to model plastic ratcheting, which is the build-up of plastic strain during cyclic loading.

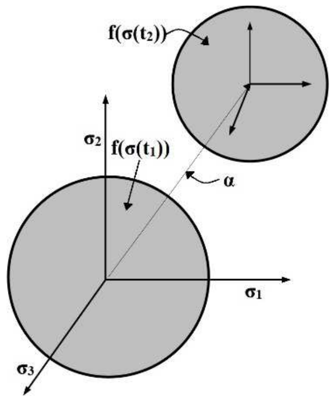


**Figure 5**

Since the considered lifeless frontal axle is subjected to cyclic loading and the yielding surface cross section stays constant, bilinear kinematic hardening approach is used for analysis.

**Kinematic Hardening**

In the course of plastic deformation, kinematic hardening causes a change in the yield stress. In uniaxial tension, plastic deformation causes the tensile yield stress to increase and the value of the compressive yield stress to decrease. This type of hardening can model the behaviour of materials under either monotonic or cyclic loading and can be used to model phenomena such as the Bauschinger effect and plastic ratcheting. The yield criterion has the following equation form

$$F(\sigma') - \sigma y = 0 \tag{24}$$

Where, $F(\sigma')$ is a scalar function of the relative stress $\sigma'$ and $\sigma_y$ is the yield stress. The relative stress is defined in equation 25.

$$\sigma' = \sigma - \alpha \tag{25}$$

Where the back stress $\alpha$ is the change in the position of the yield surface in stress space and evolves during plastic deformation.

**Bilinear Kinematic Hardening**

The back-stress tensor for bilinear kinematic hardening evolves so that the effective stress versus effective strain curve is bilinear.

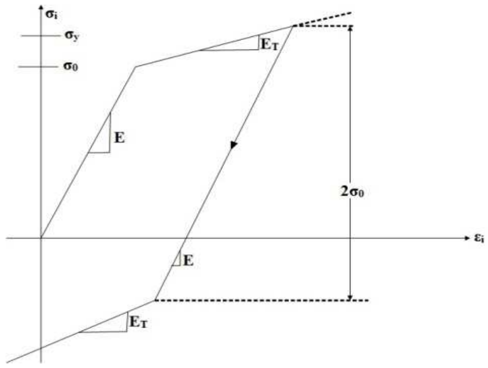


**Figure 6: Stress v/s Total Strain for Bilinear KinematicHardening**

The elastic modulus of the material is the initial slope of the curve and beyond the user specified initial yield stress $\sigma_0$, plastic strain develops and the back stress evolves so that stress versus total strain continues along a line with slope defined by the user specified tangent modulus ET. This tangent modulus cannot be less than zero or greater than the elastic modulus. For uniaxial tension followed by uniaxial compression, the magnitude of the compressive yield stress decreases as the tensile yield stress increases so that the magnitude of the elastic range is $2\sigma_0$, In this method yield stress, tangent modulus and young's modulus for the dead frontal axle model will be provided through commercial FE package to find out the true stress and true strain. The true strain obtained by this method will be a combination of elastic strain and plastic strain.

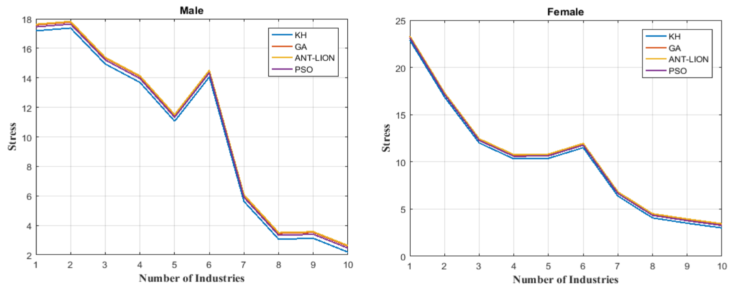


**Figure 7: Comparison of Stress Parameters**

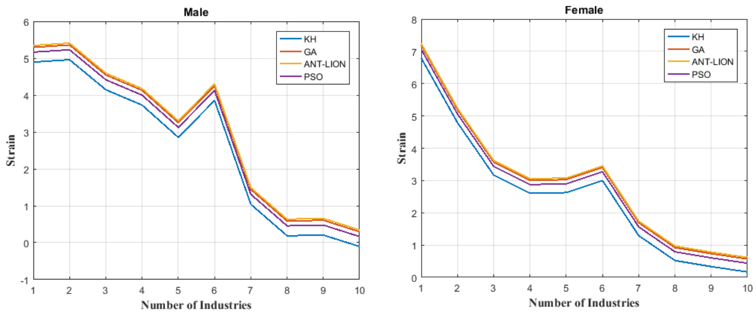


**Figure 8: Comparison of Strain Parameters**

In figure 7 and 8, the stress and strain parameters of proposed method is compared with kinematic hardening (KH) and other existing methods. The different methods such as Genetic algorithm (GA), Ant-Lion Optimization algorithm (ANT-LION), Particle Swarm optimization (PSO)are opted for the comparison. From the evaluation, the proposed method has least stress and strain parameter respectively.

## 5. CONCLUSIONS

Musculoskeletal disorder is a wide term comprising of a wide assortment of disorders including the joints and the delicate tissues engaged with moving those joints. The term incorporates different issues as low back pain, tedious strain wounds of different sorts and joint wounds. In the proposed paper, an examination has been led in 10 enterprises for assessing the musculoskeletal disorders and the parameters of MSD stress and strain in these businesses has been optimized. The hybridization of random coefficient regression analysis with whale optimization algorithm indicated better outcomes when appropriate training parameters are incorporated. The WOA has substantially reduced the time to calculate and optimize the fitness value and RCR is used as an objective function for the WOA optimization process, to generate the outputs from the inputs. The statistical outcomes got from the proposed RCR-WOA is figured by the Neuber's rule to locate the exact stress and strain parameters. A performance comparison is done to discover the effectiveness of the proposed yield utilizing Bilinear Kinematic Hardening results. The correlation of the proposed strategy with the current optimization algorithms demonstrated that better outcomes can be accomplished by picking the created technique. Ultimately, the proposed statistical evaluations ended up being an effective technique to enhance the outrageous level of stress and strain parameters of MSD in industries respectively.

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